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July 13, 1999

EX PARTE OR LATE FILED

Magalie Roman Salas
Secretary
Federal Communications Commission
445 Twelfth Street, S.W.
Washington, D.C. 20554

RE: In the Matter of Creation of a Low Power Radio Service
MM Docket No. 99-25 (RM-9208; RM 9242)
<u>Ex Parte Filing</u>

Dear Ms. Salas:

On behalf of the Consumer Electronics Manufacturers Association (CEMA), I am submitting, pursuant Section 1.1206 of the Commission's Rules, two copies of the enclosed study[1] on digital audio radio systems for inclusion in the public record in the above-captioned proceeding. CEMA is submitting the enclosed document in advance of the comment deadline in this proceeding in order to afford interested parties an opportunity to comment on the study in their filing.

Please feel free to contact the undersigned if you should have any questions about this matter.

Sincerely,

B. Bartolome

Benigno E. Bartolome, Jr.

Counsel for the Consumer Electronics Manufacturers Association

No. of Copies rec'd 0+1
List ABCDE

Enclosure

1 *Technical Evaluations of Digital Audio Radio Systems: Laboratory and Field Test Results; System Performance; Conclusions*, Final Report (December 1997)

R-3 (Audio Systems) Committee
DAR Subcommittee

Technical Evaluations of Digital Audio Radio Systems

- Laboratory and Field Test Results

- System Performance

- Conclusions

Final Report
December 1997

APPENDIX B

CEMA COMMENTS IN RM-9395

CEMA
Consumer Electronics Manufacturers Association

R-3 (Audio Systems) Committee
Digital Audio Radio Subcommittee

Technical Evaluations of Digital Audio Radio Systems: Laboratory and Field Test Results, System Performance and Conclusions

Final Report

December 1997

Prepared by the DAR Subcommittee, Report Drafting Working Group:

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Gerald Chouinard, Communications Research Centre
Ralph Justus, Consumer Electronics Manufacturers Association

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Technical Evaluations of
Digital Audio Radio Systems:
Laboratory and Field Test Results;
System Performance, and; Conclusions

Final Report

I. Introduction

The Consumer Electronics Manufacturers Association (CEMA) formed its Digital Audio Radio (DAR) Subcommittee under the R-3 (Audio Systems) Committee to organize and initiate a fair and impartial analysis, testing and standards-setting program in order to determine which DAR technical system or systems will best serve its membership, radio broadcasters, consumers at large and other affected industry groups, recognizing that complete system performance affecting sound quality (such as program source encoder/decoder, transmission system elements and the receiver) must be given primary considerations.

To accommodate concerns of some broadcasters, the National Radio Systems Committee formed its DAB Subcommittee to focus solely on In-Band/On-Channel (IBOC) FM & AM band DAR systems. This provided a forum for broadcasters to participate in DAR system evaluations without appearing to encourage DAR implementations other than IBOC. The DAR and NRSC DAB Subcommittees functioned in collaboration with each other.

Laboratory testing was performed in facilities provided to the Subcommittee at NASA's Lewis Research Center (NASA LeRC) in Cleveland, Ohio. Subjective testing of audio quality and impairment was performed at the Audio Perception Lab at the Communications Research Centre (CRC) in Ottawa, Canada

Seven proposed DAR systems (two with a second mode of operation for a total of nine implementations) were submitted to the Subcommittee for laboratory testing, and three of those for field tests. These are shown in Table 1. The laboratory and field test results are reported in the following reference documents, from which much of the data in this Report's Appendices are extracted:

> [1] Electronic Industries Association, Digital Audio Radio Subcommittee, *Report on Digital Audio Radio - Laboratory Tests - Transmission Quality Failure Characterization and Analog Compatibility*, Keller, Thomas B., Londa, David M., McCutcheon, Robert W., Toncich, Stanley S., August, 1995.
>
> [2] Consumer Electronic Manufacturers Association (a sector of the Electronic Industries Association), Working Group B "Testing" of the CEMA DAR Subcommittee, *Report of the Field Test Task Group; Field Test Data Presentation*, Culver, Robert D., December, 1996.

II. DAR System Descriptions

After a broad solicitation for proposals, the DAR systems eventually submitted for evaluation are shown in Table 2 along with the nominal frequency band of operation, audio coding, and bit rate. Further descriptions are found in Appendix 1.

Table 2
DAR SYSTEMS MAIN CHARACTERISTICS

DAR System	Frequency Band	System Class	Audio Coding	Audio Bit Rate (2 channels)
Eureka 147 #1	1452-1492 MHz	NB	MPEG Layer 2	224 kbps
Eureka 147 #2	1452-1492 MHz	NB	MPEG Layer 2	192 kbps
AT&T/Lucent	88-108 MHz	IBAC	PAC	160 kbps
AT&T/Lucent/ Amati #1	88-108 MHz	IBOC/ LSB	PAC	128 kbps
AT&T/Lucent/ Amati #2	88-108 MHz	IBOC/DSB	PAC	160 kbps
VOA/JPL	2310-2360 MHz	DBS	PAC	160 kbps
USADR-FM #1	88-108 MHz	IBOC	MPEG Layer 2	256 kbps (max.)[1]
USADR-FM #2	88-108 MHz	IBOC	MPEG Layer 2	256 kbps (max.)[1]
USADR-AM	0.54-1.7 MHz	IBOC	MPEG Layer 2	96 kbps

<u>Legend:</u>

NB	New Band	DBS	Direct Broadcast Satellite
IBAC	In Band/Adjacent Channel	USADR	USA Digital Radio
IBOC	In Band/On Channel	MPEG	Moving Picture Expert Group
LSB	Lower Side Band	PAC	Perceptual Audio Coder
DSB	Double Side Band	VOA/JPL	Voice Of America/Jet Propulsion Laboratory

Note 1: For USADR FM-1 and FM-2, variable bit rates were used. The instantaneous bit rate ranged from 128 to 256 kbps

Note 2: The Eureka-147/DAB system was designed to operate throughout the 30-3,000 MHz range. It was tested at a center frequency of 1470 MHz. in the L-band. The FM systems were tested at 94.1 MHz, the AM system at 1660 kHz, and the VOA/JPL satellite system tested at 2030 MHz.

Two systems, AT&T/Lucent/Amati and USADR FM-1, modified their systems during laboratory testing and they were subsequently re-tested on those elements for the tests conducted up to that time on all systems. The re-test results are shown in this report.

system's upper error bar fell above 0.0 provided the count shown. Third, to summarize the interaction of audio materials by systems and to indicate the size of the variability of each system, the number of times each system fell below a diffgrade of -1.0 for the 9 program test materials is presented. To take statistical error into account, the number of times that any system's lower error bar (0.45) fell "below -1.0" for any material provided the count shown.

The Eureka 147/DAB system (@ 224 kbps) is rated by expert observers to offer the best audio quality, under unimpaired conditions, when the results are examined according to these three criteria together. However, this conclusion does not reflect the various bit rates of the systems studied. Comparing the relative ratings of systems at 224 kbps, 160 kbps and 96 kbps (for example) illustrates the impact of a system's allocation of data capacity to audio source coding, instead of transmission and error correction coding. It is therefore necessary to weigh other factors like digital performance and RF compatibility (where applicable) together with the audio quality to arrive at final conclusions about a system's capabilities.

B. Impairment Performance

Laboratory tests were completed on seven digital sound broadcasting systems. Of these, four systems operate in the VHF 88 MHz to 108 MHz FM band, one in the MF band (AM), one in the S-band, and one in the L-band. Letter codes are sometimes used to denote system results in the Appendices. Systems B (E-147 192 kbps) and D (AT&T/Amati LSB) are second modes of the primary modes of Eureka-147 @ 224 kbps and AT&T/Amati DSB, respectively. IBOC systems E (AT&T/Amati DSB) and H (USADR FM-1) were modified by the proponents in the second quarter of 1995 and re-tested as systems K and L.

To examine system performance under broadcast conditions, tests were conducted to simulate the following impairments: noise (AWGN), co-channel, 1st-adjacent channel and 2nd-adjacent channel interference, multipath propagation (using both Rayleigh and Doppler fading), impulse noise, CW, airplane flutter, weak signal level, and delay spread/Doppler (a test over a range of signal delay and Doppler velocity). Appendix 3 presents detailed results of most of these, which are summarized in Table 4 below for each of the tests. Test performance thresholds were set at Threshold of Audibility (TOA) and Point of Failure (POF), which are defined in detail in [1]. Tests C-6 (Doppler) results show expert observation and commentary ratings of E1 (short or small impairments), E2 (many or continuous impairments and E-3 (audio failure).

The DAR system failure was characterized by objectively determining the TOA and POF values using noise (Test B-1), co-channel (Test B-2), and multipath with noise added (Test B-3). Subjective assessments of system failure were conducted by CRC, using the procedures detailed in Appendix U of [1], where those results are also presented. See [35] for more detail.

C. In-band RF Compatibility

Several of the systems proposed operation in the FM frequency band (and one in the AM band), already occupied by existing broadcast operations. Therefore, in-band compatibility studies comprised a significant portion of the laboratory testing. A series of tests measured possible interference to the existing analog program service caused by the introduction of the in-band DAR signal. Comprehensive tests were also conducted to measure possible interference to the ancillary subcarrier service channels by the in-band (FM) DAR signal. These tests used a group of receivers selected as representative of the existing analog consumer receiver population. These test results are summarized in Appendix 4.

Notably, the waveforms of the IBOC systems show that they place most of the digital energy within the 1st-adjacent channel (referenced to the analog signal). Subsequent references in the test results use, for example, 1st-adjacent with respect to the analog carrier frequency.

1. Digital-to-Digital Interference

The IBOC systems that use the first adjacent channel for the transmission of the digital signal have a fundamental challenge to avoid interference from the digital signal which may be operating on a undesired first-adjacent FM channel. The overlapped portion of the RF spectrum by the two digital signals can result in a significant reduction of digital coverage as compared to the host FM analog signals which are only adjacent. The interference between the first-adjacent digital signals of FM stations that have analog signals that are second-adjacent is also critical but can be improved by system design.

With the exception of the system that transmits some of the digital signal underneath the analog signal (USADR FM-2), the digital performance of stations that have co-channel analog host signals exceeded the FCC prescribed D/U ratios (less interference).

The test results show in-band DAR systems first-adjacent interference (TOA) to be approximately 18-21 dB worse than the FCC-specified FM-to-FM protection ratio (desired-to-undesired, or "D/U") of +6 dB D/U, and second-adjacent interference (TOA) to be 23-43 dB worse than the FM protection ratio of -40 dB D/U. This result is heavily dependent on receiver type.

The AM DAR system co-channel D/U measured 27 dB at TOA. The first-adjacent channel D/U measured 32 dB at TOA This contrasts with the FCC's 6 dB D/U adjacent-channel protection ratio. The second-adjacent interference was about 1 dB less than the first-adjacent.

Test results show first-adjacent interference up to 25 dB worse than the FCC FM RF protection ratios and second adjacent interference up to 22 dB worse (with narrowband car receivers). This measured performance will not allow satisfactory operations of in-band systems under the present table of allocations when both digital and analog systems are contemplated to be used.

Three receivers were used for the AM tests, Delco auto, Denon Hi-Fi, and Panasonic portable. The Denon NAB super radio was operated in both the narrow and wideband modes. For the first adjacent interference tests, the addition of the IBOC digital signal added to the analog had little effect on the receiver noise. The second adjacent digital signal increased the analog reception interference by 15 to 20 dB over the reference analog second-adjacent interference at the strong desired analog signal level.

4. IBOC-to-Host Analog Interference

The worst degradation to the host station was evident from the USADR FM-1 and ATT/Lucent/Amati DSB and LSB IBOC systems which exhibited objective S/N degradation of reception of "host" analog signals by 27 dB, 26 dB and 26 dB (respectively) on the Pioneer receiver, with a corresponding subjective impairment quality assessment of -3.0 (much worse) under strong signal conditions. The Denon and Panasonic receivers exhibited S/N degradation in the 16-25 dB range, depending on the IBOC system. The Delco and Ford car receivers showed modest to no S/N degradation with insertion of the IBOC signal.

This interference is most pronounced at moderate to strong RF signal levels. The noise is detected by PLL stereo decoders but can be eliminated with the use of special circuitry (e.g., using Walsh function detection or 114 kHz filtering). A large part of the present population of stereo receivers employ PLL detectors and thus are subject to this noise increase.

<u>Baseband Noise Increase</u>
Testing revealed an unexpected decrease of the recovered baseband stereo signal SNR to 40 dB when IBOC signals were present in the channel. Further study (see Appendix 6) concluded that the characteristics of the FM limiter and detector may be the mechanisms responsible for increasing noise with modulation in the presence of a non-coherent nearby RF signal. The design of a detector for FM broadcast receivers is normally wideband in nature, typically from 600 kHz up to 1 MHz in bandwidth. This bandwidth is required in order to keep the phase delay of the composite stereo signal very low, especially for the L-R sidebands, in order to recover a high quality stereo signal. The limiter section introduces a non-linear process and, with the detector containing non-linear devices, mixing of the two signals occurs. The detector is essentially a mixer with one input being a variable phase-shifted version of the other. If two input signals fall into the linear range of the detector, the output will be proportional to the frequency difference between them.

IV. Field Test Results (See Appendix 13)

Field testing examined DAR systems under actual transmission and reception conditions. These types of tests are often used to assess whether laboratory testing and impairment simulations were meaningful and realistic, in which case we would expect a certain degree of corroboration between lab and field results. Field testing also provides a "sanity check" to see whether important radiofrequency conditions may not have been examined during laboratory testing.

A. Reception reliability

Field testing sought to examine, among other things, the practical reception of DAR signals in the mobile environment as would be experienced by listeners. Coverage maps of the San Francisco Bay area and downtown San Francisco representing these results are presented in Figures IV-1 to IV-8 below. These figures show the expected coverage as color coded background as well as the observed performance from the field tests as color coded routes. These results typically show good correlation with laboratory results. The coverage maps were produced with the CRC-COV software program to which were added the test routes using the MapInfo software package [36]. Expected coverage was predicted using the propagation routines contained in CRC-COV for a variety of reception reliability factors and signal strengths and the actual DAR reception performance indicated by the colored routes was extracted from the observations reported in the printed DAR Field Test Report. These maps are also located at the web site: www.cemacity.org/testdar

The coverage for the EU-147 systems and the AT&T IBAC system was predicted using the CRC software routine "PREDICT" (part of CRC-COV) which uses the terrain topography (USGS data for San Francisco) and morphography (constructed manually from maps) and applies physical optics principles to predict the field strength at specified locations. In the case of the two EU-147 systems, the colored background was produced with the field strength set at the value corresponding to the threshold of operation of the receiver and the percentage probability of that signal being received was used as the variable for color coding the background based on a constant field strength standard deviation of $\sigma = 5.5$ dB. Three decision points are used; 95%, 50% and 5%, yielding four ranges of coverage probability; 95% and better, 5% and less and the 45% probability spread above and below the median 50% probability. The transmission parameters used in this prediction were those actually used in the field and are listed in Tables 1-3 of Appendix 13. In the case of the single transmitter, only the parameters of the second column of the Table (Mount Beacon) were used whereas in the case of the SFN, all the parameters include in Table 1, Appendix 13 were used.

The observed coverage is displayed along the actual routes where these observations were made and is color coded with the audio events reported along the test routes, that is 'Impaired' (green) and 'Muted' (red), with the remainder of the route being classified as Clear of any audio impairments (blue). The position along each route for each

Figure IV-1:
Eureka-147 SFN
ediction and Measurements
San Francisco
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Figure IV-2:
Eureka -147 SFN
Prediction and Measurements
Downtown Area
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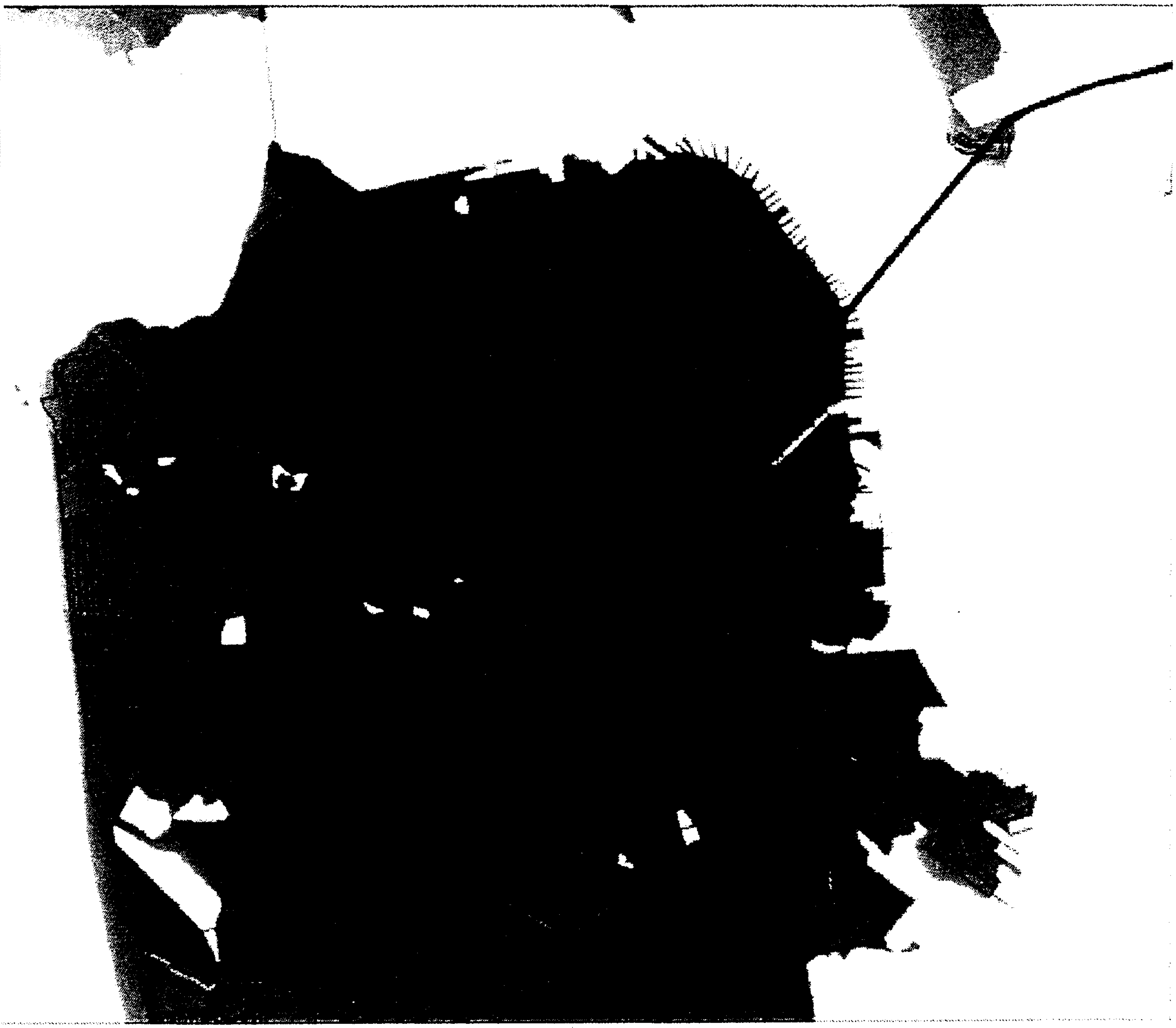

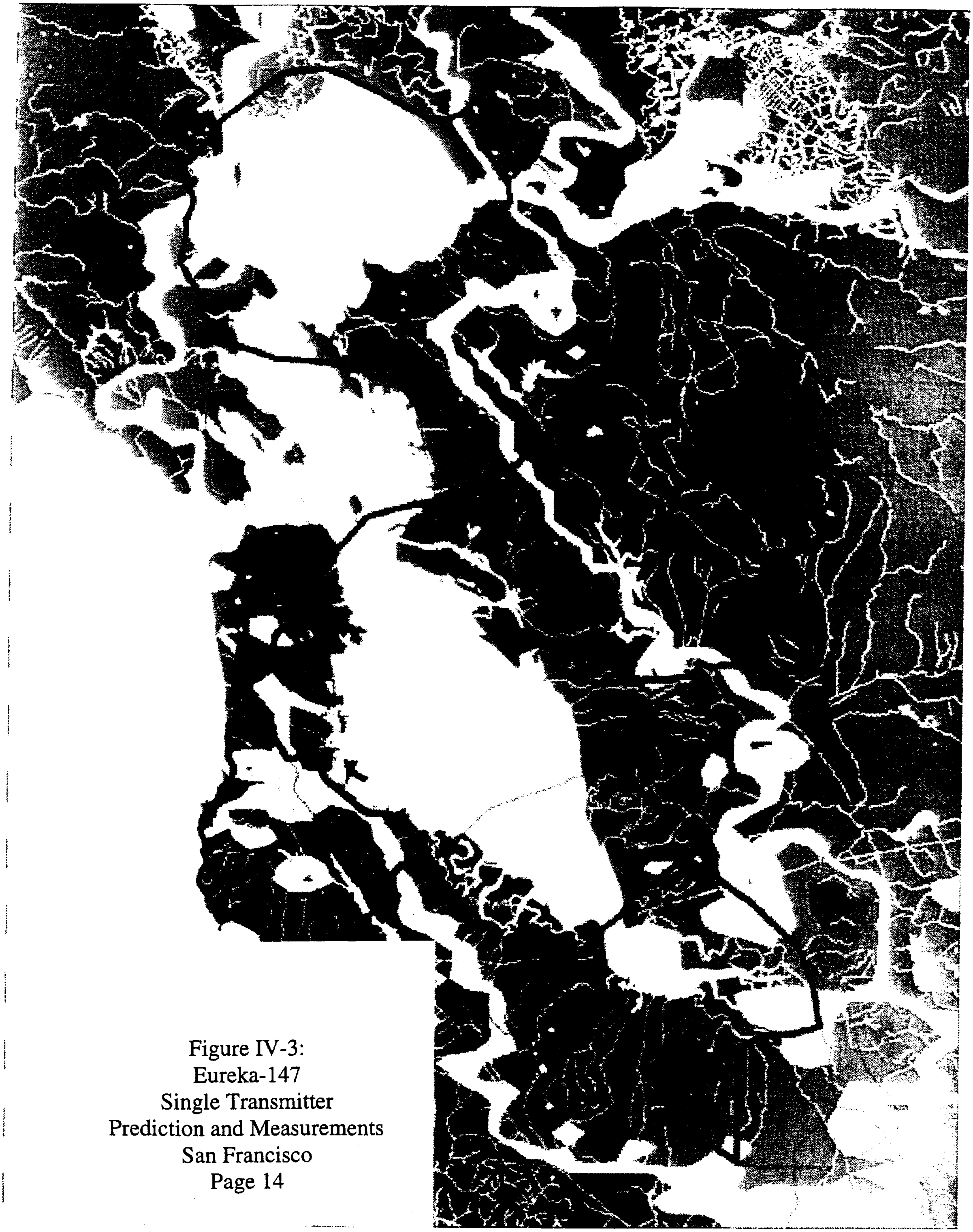

Figure IV-3:
Eureka-147
Single Transmitter
Prediction and Measurements
San Francisco
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Figure IV-4:
Eureka-147
Single Transmitter
Prediction and Measurements
Downtown Area
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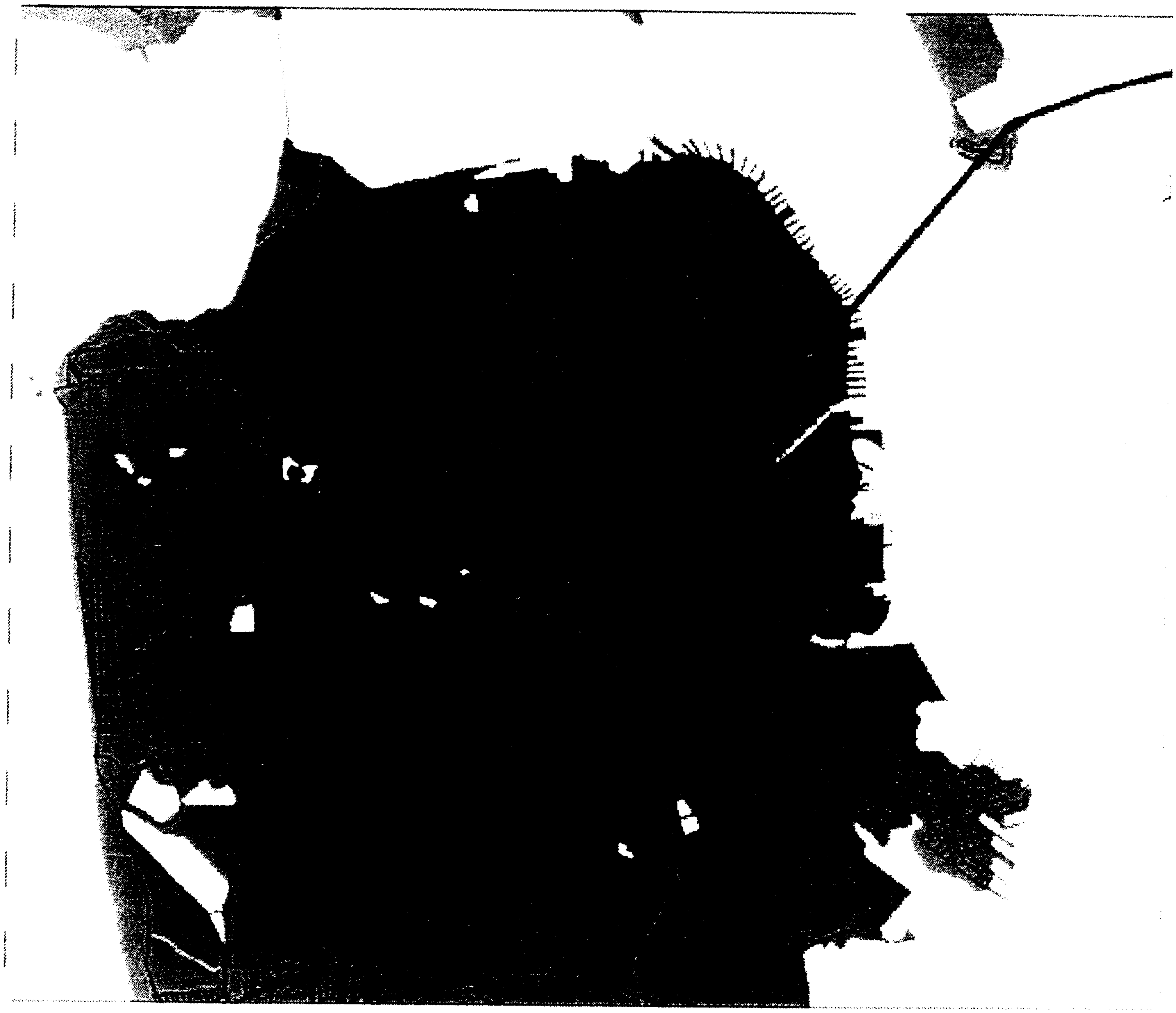

Figure IV-5:
AT&T/Lucent (IBAC)
Prediction and Measurements
San Francisco
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Figure IV-6:
AT&T /Lucent (IBAC)
Prediction and Measurements
Downtown Area
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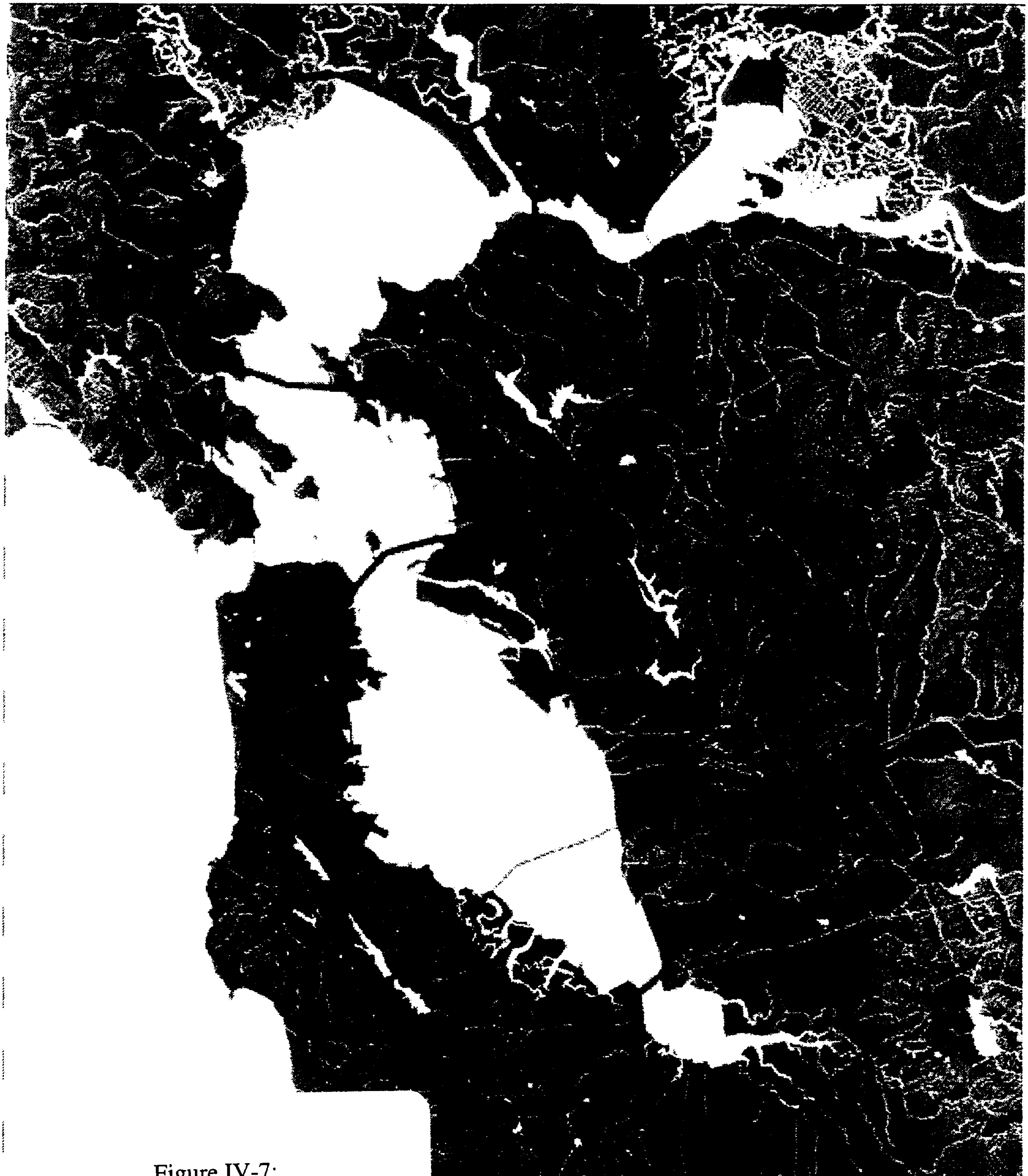

Figure IV-7:
VOA/JPL
Measurements and Topology
San Francisco
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Figure IV-8:
VOA/JPL
Measurements and Topology
Downtown Area
Page 19

Legends for Figures IV-1 through IV-8

(these maps are also available on the web at: www.cemacity.org/testdar)

Figure IV-1, IV-2, IV-3 and IV-4 (Eureka-147/DAB SFN & Single)

Predicted Coverage, in term of Service Availability (SA @ 43 dBµV/m):

Blue:	95% < SA
Green:	50% < SA < 95%
Yellow:	5% < SA < 50%
Orange:	SA < 5%

Measured Coverage, in terms of audio quality:

Blue:	Clear
Green:	Impaired
Red:	Muted

Figures IV-5 & IV-6 (AT&T/Lucent)

Predicted Coverage, in term of Field Strength (FS):

Blue:	66 < FS	dBµV/m
Green:	60 < FS < 66	dBµV/m
Yellow:	54 < FS < 60	dBµV/m
Orange:	48 < FS < 54	dBµV/m

Measured Coverage, in term of audio quality:

Blue:	Clear
Green:	Impaired
Red:	Muted

Figures IV-7 & IV-8 (VOA/JPL)

Topography: shaded elevation with 50m (IV-7) and 25 m (IV-8) contour lines

Measured Coverage, in term of audio quality:

Blue:	Clear
Green:	Impaired
Red:	Muted
Grey:	File Corrupted

classification was plotted directly from the printed linear graph referenced to the written landmark locations. An examination of Figures IV-1 to IV-4 shows very good correlation of observed reception classification with predicted signal strength availability.

In the case of the AT&T IBAC system, the expected coverage was predicted using the same PREDICT routine and displayed with the CRC-COV program. The transmission parameters were as indicated by AT&T (i.e., 5 kW ERP almost omnidirectional [with an assumed drop in gain of 3 dB towards North caused by nearby tower structures] and antenna height above sea level of 352 m). The percentage of signal being received at or above a given level was set at 50% and field strength levels around the 54 µV/m typical FM Grade B protected contour which is also a practical contour for the limit of reception of analog FM radio. Four predicted contours were actually used (i.e., 48, 54, 60 and 66 µV/m). This range of contours should encompass the appropriate contour to be used for estimation of coverage, which was problematic to define due to an 18 dB received attenuation error caused by a measurement hardware configuration. Again, the audio events classified according to Clear, Impaired and Muted as explained above, are shown along the test routes.

The illustration of service for the VOA/JPL S-Band satellite system, Figures IV-7 and IV-8, does not show signal strength, which is for all practical purposes constant over the area of testing, but instead shows the topography of the area using a graded gray scale as well as contour lines. The audio performance characterization is presented as color coded lines as in the former cases along each test route. The satellite signal (which arrived at an elevation angle of approximately 23 degrees from the West) is subject to blockage by either terrain such as mountains and hill as well as nearby objects obstructing the line-of-sight to the satellite such as foliage, buildings, signs, overpasses, etc. The nearby obstructions explain the losses of signals in the cases where the surrounding terrain was flat.

The above figures represent, in a color coded fashion, the reception impairments observed along the test routes and constitute an effective means of identifying when the system under test failed either because of local obstructions, multipath or because it was simply out of its coverage range. This information is critical to an in-depth assessment of performance under field conditions. Illustrative of this are the numerous instances on some routes when systems other than the VOA/JPL system were in the failure mode (e.g., out of coverage range) and the VOA/JPL system had unimpaired reception (without blockage). Conversely, on other portions of test routes, the terrestrial systems did well, being within their coverage area whereas the VOA/JPL satellite system experienced service outage caused by line-of-sight obstruction to the receiver (blocked by terrain, buildings, road signs, trees, etc.).

The field test results can also be represented in a more concise fashion by totaling the percentage of reception reliability on all test routes given types of areas as shown in Table 6 below. These summary results need to be used with caution because they deal with different outage mechanisms which affect different systems differently. The colored maps presented above are more meaningful in trying to interpret the results of these field tests.

Route	Eureka- 147	Eureka- 147 (single)	AT&T	VOA/JPL
Perimeter	99.2	95.1	88.9	71.4
Downtown	99.5	99.6	92.6	40.5
North	76.4	84.6	65.2	93.7
South	92.4	92.4	27.5	94.5
West	54.7	32.5	37.3	83.3
East	68.1	47.4	55.4	80.1
Average	81.7	75.3	61.2	77.3

Table 6: Field Test Audio Observations of Clear Signal Quality
(% of Total Measured Data Points)

Although the summary results contained in Table 6 do not differentiate whether the signal losses are caused by local obstructions, multipath or by lack of signal, the results on the Downtown and Perimeter routes are especially meaningful in that ample signal strength was present for all systems, these routes are representative of actual urban environments and the relative degrees of system performance is consistent with laboratory expectations -- except that the severe impairment results of the VOA/JPL system caused by signal blockage was clearly limiting because of the minimal fade margin and relatively low elevation angle to the satellite.

B. Indoor Testing

A series of tests were conducted on all systems to measure reception performance inside a building. However, the computer data recordings suffered severe contamination due to unknown reasons and was not recoverable. These data errors were not discovered until the experimental L-band authorization had expired and, thus, repeating these indoor measurements could not be conducted on all systems during the same period. However, the video and audio recordings could be examined manually to extract RF levels and degree of audio impairment. The DAR Subcommittee deemed this too costly (time and resources) to complete. This is an area where further studies of the recorded data might be revealing, if needed.

C. Further Analyses Possible

Further analysis of each system can be undertaken, using the recorded data, to gain more information about the nature of RF conditions during failure, signal strength and coverage, margin to threshold, etc. Also interesting would be further assessments of the extent that analog FM signals, transmitted from Mt. Beacon and recorded simultaneously during DAR system tests, reveal impaired quality or not. Such analysis was not part of the field test program, though the data necessary for this analysis was collected. Further analysis of the recorded data on the various systems could also answer questions about coverage and quality of service relative to analog FM stations.

D. Field Test Conclusions

The Eureka-147 system in both its single and multiple transmitter configurations exhibited excellent reception in areas where adequate signal strength was provided (i.e., over most of the test area). Further examinations and analysis of these data, though technically intriguing, are unlikely to reveal significant information about system service quality and coverage above that already disclosed by the laboratory test results.

The AT&T/Lucent (IBAC) system performed well within its estimated coverage area, with the exception of occurrences of impairments occurring on urban routes which are presumed to result from wide-band multipath fades and shadowing.

The VOA/JPL system exhibited consistent reception over the whole extent of the test area, although significant signal losses were experienced. These signal losses at S-band frequencies were severe and coherent with path blockage by all objects, including buildings signs, trees, etc.

Some supplemental information indicates that the service reliability in field tests was similar to predicted lab results. More detailed analyses of predicted and measured field test performance has not been performed. System proponents did not provide their own assessments though this information was requested.

V. Overall Evaluations Based on Performance Objectives

The DAR Subcommittee established the following performance objectives as the basis for its evaluations of DAR systems:

1. CD quality sound
2. immunity to multipath and other interference
3. no objectionable interference to other services
4. minimization of transmission costs and reception complexity and costs
5. additional data capacity
6. degradation at the reception area threshold with a minimum of objectionable artifacts

The DAR Subcommittee testing provides data for thorough evaluation of the systems relative to objectives Nos. 1, 2, 3, and 6, above. Some evaluation or comment on objectives Nos. 4 and 5 is possible and discussed below. Further analysis of the present data and/or proponent supplied data could provide more information.

Comparison of the DAR system performance to standard analog FM service was not one of the six fundamental objectives and arose late in the field test plans. If desired, FM service comparisons can be made using the data collected in field tests.

The degree to which the tested systems met these objectives (excluding costs and complexity) are fully detailed by the testing program and the results substantiate the following conclusions:

1. Audio quality (CD quality sound)

The USADR AM system showed audio quality in an unimpaired channel judged "very annoying" compared to the reference CD quality (whether sampled at 32 kHz or 48 kHz). This fails to achieve a minimum level of acceptability.

The FM in-band IBOC & IBAC systems exhibited two major deficiencies: (1) impaired channel digital performance and (2) inherent incompatibility with existing analog FM spectrum occupancy and reception. This makes further assessment of their relative audio quality merits irrelevant.

The Eureka-147/DAB system is shown to offer the highest quality audio (@ 224 kbps).

2. Immunity to Multipath and Other Interference

A. Multipath Performance.

Qualitative results of the multipath testing are shown in Table 7, below. This considers both Rayleigh and Doppler fading simulations as well as Airplane Flutter and the Delay Spread/Doppler results that examined the limits of performance.

Table 7 – Multipath Results

Multipath Scenario	Eureka-147 224 kbps	AT&T	AT&T/Amati dsb	USADR FM-1	USADR FM-2
Multipath 1 (Rayleigh)	Very Good/Fair	Good/Fair	Very Good/Good	Fair/Good	Total Failure
Airplane Flutter	Very Good	Good	Very Good	Fair	Very Poor
Multipath 2 (Doppler)	Very Good	Good	Good/Fair	Fair	Total Failure
DelaySpread/ Doppler	Very Good	Good	Good/Very Good	Poor	Total Failure
Overall	**Very Good**	**Good**	**Very Good/Good**	**Fair**	**Total Failure**

Overall, the Eureka-147 system exhibited excellent capabilities to handle all types of fading environments. Its wide bandwidth channel (1.5 MHz) was designed to counter both frequency selective and flat fading multipath.

B. Other Interference.

Noise, co-channel, impulse noise and CW impairment results serve to characterize the systems' susceptibility to these types of impairments. With noise and co-channel tests, adding multipath impairments drastically changed the system's performance. The failure margin (the difference in values between TOA and POF) shows how abruptly or gracefully systems fail with signal level variations. In the presence of additive Gaussian noise or co-channel interference, the VOA/JPL and AT&T systems exhibited a "brick wall" failure with a failure margin ranging from 0.4 dB to 0.8 dB. The USADR FM-2 system had the slowest degradation with a failure margin of 2.8 dB. In the mobile multipath channels, systems tested exhibited slower degradation than in the "static" channels (i.e., co-channel and noise) with failure margins ranging from 2.5 to 7.5 dB.

A more detailed examination of these results can be found in [35], along with assessments of power and spectral efficiencies of DAR systems with the various transmission impairments considered. There, it is presented that: (1) the VOA/JPL system was the most power efficient in a simple Gaussian channel; (2) tests have shown that systems expected to operate adequately in the mobile multipath environment presently have a spectrum efficiency limited to about 1 bit/s/Hz. This approach to examine DAR system capabilities deserves further study.

3. No Objectionable Interference To Other Services & In-band Compatibility

(a) IBOC-to-Host Interference

All the FM IBOC systems tested caused an unacceptable degradation in the host stations reception quality. Only a few receiver circuitry types in current use resist this degradation (Walsh function detection or 114 kHz filtering) and those represent less than 10% (estimated) of the existing receiver population of in-use sets. Accordingly, this represents a fundamental design deficiency with IBOC systems -- they are not compatible with existing broadcast reception.

Further, all the FM IBOC systems severely degraded the performance of host station FM subcarriers on 67 kHz and 92 kHz, and IBOC composite degradation was observed to other stations' subcarrier operations.

(b) In-Band Digital-to-Digital and Analog-to-Digital Interference

All the tested FM IBOC systems cause extensive digital-to-digital interference on first-adjacent channels. The USADR systems also caused this interference on second-adjacent channels. The resulting digital coverage is severely limited by interference which would result from the existing frequency occupancies of analog broadcast stations. Second-adjacent interference might be improved by system design modifications. Analog-to-digital interference might disappear with a migration to an all digital IBAC operation. IBOC systems, however do not contemplate the cessation of all analog broadcasting.

The AT&T/Lucent IBAC system has limited potential coverage due to presumed placement on frequencies subject to widespread first-adjacent and second-adjacent interference from existing FM broadcast signal levels. Although the system contemplates a total transition to digital, finding sufficient spectrum to maintain totally redundant analog and digital operations during transition is problematic in many areas of the country and impossible in major markets.

(c) IBOC Digital-to-Analog Interference to Other Stations

Digital-to-analog 1st-adjacent interference is up to 25 dB worse than FM-to-FM, and 2nd-adjacent interference is up to 22 dB worse. The resulting interference to existing analog broadcast reception was never foreseen in the FCC's planning of separation distances between transmitters. Further, the RF emission mask was never intended to apply to intentional insertion of continuous signals, but rather to protect from unintentional spurious and sporadic signals from FM composite modulation. Therefore, separation distances between transmitters would need to be larger than currently exist under FCC assignments to protect from interference and this is unacceptable to consider now. Without a total migration to digital-only transmission, a scenario not generally anticipated by existing broadcasters, such increased interference would remain forever.

(d) Finding

The following DAR systems fail to achieve a minimum acceptable level of performance because of the observed interference to the host FM (and AM) station as well as interference to and from other stations. For the reasons discussed, they are not recommended for further consideration.

AT&T/Lucent Technologies/Amati Communications Corporation (LSB & DSB)
AT&T/Lucent Technologies
USADR FM-1
USADR FM-2
USADR AM

4. Minimization of transmission costs & reception complexity

This has not been studied in depth, however it is noted that the Eureka-147 system currently has 4^{th}+ generation receivers and mature IC designs available.

5. Additional data capacity

All the systems posed some degree of ancillary data capacity, however only the Eureka 147 system provided explicit plans and specifications for such service during this test process. That system has the capability for dynamic data rate/channel allocation which provides a superior opportunity for future exploitation. As tested, the system had five audio program data channels of various bit rates plus extra data. The multiplex could be easily changed to other mixes of audio channel and data, and receivers will automatically track the change in real time. The system can be configured to carry data in 3 types of transmission: Fast Information Channel (FIC) from 0 to 20 kbps; Program Associated Data (PAD) from 0 to 64 kbps, and; Main Service Channel (MSC) from 0 to 1.3 Mbps (less what is being used for audio).

6. Graceful Degradation

Extensive discussion and experiments of systems' abilities to have a graceful degradation of the digital signal at the edge of the coverage area revealed that this Subcommittee objective may have been unrealistic. The nature of digital system failure at the threshold -- the "cliff effect" where a signal is perfect, then crashes rapidly -- is an inherent feature of both audio and video digital systems. The margin from threshold of audibility of impairment to the point of failure for DAR systems was small (1-2 dB). Only USADR claimed to have a graceful degradation during impaired conditions, but as seen in the